

United States Patent Application for:

**MICROMACHINED INTEGRATED FLUID DELIVERY
SYSTEM WITH DYNAMIC METAL SEAT VALVE
AND OTHER COMPONENTS**

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1 [0001] **MICROMACHINED INTEGRATED FLUID DELIVERY SYSTEM**
2 **WITH DYNAMIC METAL SEAT VALVE AND OTHER COMPONENTS**

3 [0002] Related Applications

4 [0003] This application is a continuation-in-part of U.S. Application Serial No.
5 10/328,135, filed December 20, 2002, which is currently pending.

6
7 [0004] Field of the Invention

8 [0005] The present invention pertains to a space-conserving integrated fluid delivery
9 system which is particularly useful for gas distribution in semiconductor processing
10 equipment. The present invention also pertains to an on/off valve of compact design,
11 adapted for allowing or preventing the flow of gases in semiconductor processing
12 applications. It also pertains to other integrated fluid components, such as filters, pressure
13 sensors, fluidic thermal sensors, laminar flow elements, pressure regulators, control valves,
14 flow restrictors, and check valves, which may be integrated to different degrees into the
15 structure of a fluid delivery network architecture.

16 [0006] Brief Description of the Background Art

17 [0007] In chemical processing which relies on fluid handling in general, and particularly
18 when the fluids to be handled are hazardous and reactive materials, improved system leak
19 reliability and careful integration of the fluid handling devices and network architecture into
20 the general process system is of paramount importance. In addition, it is important that all
21 of the component devices used in the fluid handling be well integrated into the overall fluid
22 flow network architecture to ensure system leak reliability, provide size reduction, and
23 enable flexible control. In applications such as semiconductor processing, for example, the
24 fluid component devices must also exhibit particular capabilities which ensure cleanliness
25 of the fluid delivery process, so that the solid state devices being fabricated will not be
26 contaminated, affecting performance and reliability.

1 [0008] One of the most widely used fluid component devices, which has been a source
2 of particulate contamination in the past, is the on/off valve. The fluid on/off valve must
3 exhibit several particular capabilities. First, it must allow and prevent fluid flow, including
4 virtually absolute shutoff to as little as about 1×10^{-9} cc/sec. of helium at a pressure
5 differential of one atmosphere, as well as virtually zero outleakage (also 1×10^{-9} cc/sec.
6 helium at a pressure differential of one atmosphere). Helium is typically used for leak
7 testing because of its small atomic size, diffusivity and high mobility. This is indicative of
8 the ability to prevent exposure of the environment of often extremely toxic and corrosive
9 process fluids. The fluid on/off valve must also maintain the required high purity of the
10 fluids, contributing no appreciable amount of particulates, which are typically generated by
11 wearing parts within the wetted portion of the valve. The fluid on/off valve must possess
12 good resistance to the corrosive properties of the fluids. Due to the toxicity of a number of
13 the fluids transported, very high system leak reliability and long service life (avoidance of
14 the need to shut down and change out parts) are of great importance. Also of importance are
15 a compact design, and a reasonable cost.

16 [0009] During work on the present conserved space integrated fluid delivery system, an
17 on/off valve was designed which provides many of the advantages discussed above. In
18 addition to the description of the integrated fluid delivery system, that on/off valve is
19 described in detail herein.

20 [0010] The present invention takes the concepts regarding an integrated fluid flow system
21 to a new level of integration which permits not only improved functionality, but also
22 considerable cost savings in fabrication. As a result of the reduced fabrication cost, and a
23 properly balanced level of modularity, it is possible to reduce maintenance costs for the fluid
24 flow system by replacing integrated modules rather than shutting the system down for long
25 maintenance and repair operations with respect to individual component devices (which are
26 part of the integrated module in present designs).

27 [0011] The importance of very high system leak reliability and long service life

1 (avoidance of the need to shut down and change out parts) in the semiconductor industry is
2 illustrated by the factors which must be considered with respect to the design of an on/off
3 valve. For example, in a fluid flow valve, each of the fluid-wetted parts must be fabricated
4 from a highly corrosion-resistant material. In the general chemical processing industry,
5 process control valves frequently employ corrosion-resistant plastic or elastomeric valve
6 seats. Metal valve seats provide advantages in terms of minimizing valve seat maintenance
7 and maintaining fluid cleanliness; however, metal valve seats require high seating forces,
8 compared to polymeric seats, in order to reliably provide a tight shut-off. As a result, all
9 valves with metal valve seats are typically larger in size and cost significantly more than
10 valves with polymeric seats. Additional advantages of all-metal valves include their ability
11 to be heated to high temperatures and their superior moisture dry-down characteristics.

12 [0012] One example of an advantageous valve having metal-to-metal seating for
13 controlling the flow of a gas employs a flexible metal diaphragm mounted in the valve so
14 the diaphragm can be moved into and out of sealing contact with the metal seat to close and
15 open a gas passage, respectively. The valve seat has a rounded metal sealing projection with
16 a relatively small cross-sectional radius around the seating section extending about the gas
17 flow passage. The flexible metal diaphragm is moved into and out of sealing contact with
18 the metal sealing projection of the seat by an actuator which employs a metal backing
19 member which forcefully contacts the diaphragm during narrowing or closing of the gas
20 flow passage. For additional information about this all-metal valve, one skilled in the art
21 should refer to U.S. Patent No. 5,755,428, of Louis Ollivier, issued May 26, 1988.

22 [0013] As described above, the potential problems of process fluid outleakage and/or
23 process fluid attack on valve mechanicals may be addressed using a diaphragm valve having
24 metal wetted parts (among other closing techniques). However, in previous designs, when
25 the valve seat is metal, a particularly high seating force is required, compared with polymeric
26 valve seats. Typically, when a plastic seat is used for a high cycle application, plastic
27 deformation of the seat leads to lower valve reliability. The valve is typically operated in

1 a normally-closed position, to provide a “fail safe” condition in the event of a loss of motive
2 power (electric or pneumatic) to the actuator. When the actuator design incorporates a
3 spring (or springs) capable of applying the large force required for a metal valve seat, the
4 spring is typically large, on the order of 3 cm to 10 cm tall, and the valve itself is expensive,
5 often costing around 5 - 6 times the price of a comparable capacity plastic-seated valve. It
6 would be highly desirable to have a corrosion-resistant on/off valve, where all of the fluid-
7 wetted parts are metal; where the valve is compact in design, and well integrated into its end
8 use application.

9 [0014] With respect to an integrated network architecture of fluid flow devices and
10 channels with an integrated control system, there is a constant need for a higher degree of
11 integration, simplification and ease of operation. In addition to performance and handling
12 advantages, the integrated fluid flow system must be cost competitive. This means that
13 fabrication methods for the various fluid handling devices, interconnecting network
14 architecture and integrated control system need to be easily scalable in tooling for mass
15 production, variable production demand and cost-effective NRE (Non-recurring
16 Engineering) charges. The present invention provides substantial advantages in all of these
17 areas.

18 [0015] SUMMARY OF THE INVENTION

19 [0016] The present disclosure pertains to a space-conserving integrated fluid delivery
20 system which is particularly useful for gas distribution in semiconductor processing
21 equipment. The present invention is applicable to various integrated fluid handling devices,
22 including filters, pressure sensors, fluidic thermal sensors, laminar flow elements, and an
23 integrated on/off valve of compact design, adapted for precisely controlling the flow of gases
24 in semiconductor processing applications. The integrated fluid delivery system and the
25 integrated fluid handling devices such as the on/off valve employ layered substrate
26 technology to varying degrees, depending on the device. In the layered substrate technology,

1 fluid flow channels, portions of component device structures, and in some instances the
2 complete component device structure are integrated into a fluid handling, interconnected
3 network architecture. The fluid flow channels, are fabricated using patterned metal and
4 metal alloy layers, which may be patterned by any method known in the art, but which are
5 advantageously chemically or electrochemically etched and then adhered to each other to
6 produce a layered substrate. One method which is advantageously used to adhere the
7 patterned metal layers is diffusion bonding. Portions of component device structures and
8 complete device structures are also fabricated using patterned metal and metal alloy layers
9 which are adhered together, typically simultaneously with the fluid flow channels to form
10 a fluid flow network. Diffusion bonding of partially integrated and fully integrated device
11 structures into a layered substrate is described in detail herein.

12 [0017] One embodiment of an integrated on/off valve, as adapted for use in controlling
13 process fluids in semiconductor processing operations (by way of example and not by way
14 of limitation), is fabricated so that fluid-wetted surfaces of the valve are constructed from
15 a corrosion-resistant metal or metal alloy, including a metallic diaphragm separating the
16 wetted section of the valve from the non-wetted drive section of the valve. In the wetted
17 section, process fluids enter through one or more entrance ports. The exit port from the
18 wetted section comprises an annular metallic valve seat. The valve seat is formed as, or
19 upon, an inner lip of the exit port. When the valve is closed, the fluid flow is interrupted by
20 a section of the diaphragm being pressed tightly against the valve seat. Fluid may flow in
21 either direction.

22 [0018] The metal valve seat is advantageously a dynamic seat which deforms elastically
23 when pressed upon by the diaphragm and its backing disk, so that the seat recovers each time
24 the valve is closed and reopened, rather than being permanently deformed by the valve's
25 closure.

26 [0019] In the valve's wetted section, metal-to-metal bonding can advantageously be
27 accomplished using diffusion bonding. Diffusion bonding is a direct bonding process which

1 provides strong bonds that do not absorb or release process fluids, and do not contribute
2 impurities to the process fluids, as a welded joint might do. It is important that no adhesive
3 (or adhesive residue) be present on the wetted flow path. Diffusion bonding permits the
4 formation of complex shapes without costly milling (machining).

5 [0020] In order for diffusion bonding to be most effective, the metal surfaces that are to
6 be bonded must have an average surface roughness within the range of about 0.1 Ra to about
7 30 Ra maximum prior to diffusion bonding. Typically, the metal surfaces to be bonded
8 have a surface roughness within the range of about 0.5 Ra to about 10 Ra maximum. We
9 have found that diffusion bonding works quite well when the metal surfaces have a surface
10 roughness within the range of about 1.5 Ra to about 3.0 Ra maximum.

11 [0021] In some cases, the metal surfaces will need to be pretreated by electropolishing or
12 mechanical planarization to have the desired surface roughness prior to diffusion bonding.
13 For example, stainless steel can be chemically or electrochemically etched using ferric
14 chloride according to standard methodology known in the art. A process for electrochemical
15 etching of difficult to etch materials such as HASTELLOY® is described in U.S. Patent No.
16 6,221,235, issued April 24, 2001, to Gebhart. Certain materials may require mechanical
17 planarization to smooth down the surface prior to the performance of a chemical or
18 electrochemical etching process to obtain a surface roughness within the desired range.
19 Mechanical planarization of metal surfaces can be performed according to techniques known
20 in the art.

21 [0022] In other instances, the metal surfaces may be manufactured with the desired surface
22 roughness, and may need no electrochemical or mechanical pretreatment prior to diffusion
23 bonding. For example, the ASTM standard for surface roughness for stainless steel sheets
24 (as rolled) is 0.5 Ra to 4.0 Ra (ASTM 480 BA – bright annealed). No electropolishing is
25 needed for this material prior to diffusion bonding. However, after diffusion bonding, it is
26 necessary to treat the steel surfaces which will be in contact with corrosive materials to
27 improve the corrosion resistance of such steel surfaces.

1 [0023] In the valve's non-wetted drive section, a sliding cylinder moves up and down,
2 pressing a lower horizontal member, which typically includes a convex contacting surface,
3 against a diaphragm, which is in turn pressed against the valve seat to close the valve. The
4 diaphragm is permitted to move away from the valve seat to open the valve. The sliding
5 cylinder has an upper horizontal member connected to a smaller, lower horizontal member
6 by a vertical member. The sliding cylinder may be of single piece construction. The valve
7 is maintained in a normally-closed position by a spring force applied at the top of the upper
8 horizontal member of the sliding cylinder. The spring drives the lower horizontal member
9 of the sliding cylinder, which includes a convex surface (acting as a backing disk), against
10 the diaphragm. The sliding cylinder has a gas-tight seal around the perimeter of both the
11 upper horizontal member and the lower horizontal member. A typical gas-tight seal is a
12 polymeric "O"-ring. The valve is opened by pneumatic force from a pressurizing gas which
13 is applied in a space between the upper horizontal member and the lower horizontal member
14 of the sliding cylinder. When the pressurizing gas is applied within the space, the
15 pressurizing gas acts to compress a spring or spring assembly located above the upper
16 horizontal member, permitting the sliding cylinder to rise, and permitting the diaphragm
17 beneath the lower horizontal member to rise above the metallic seat, enabling fluid to flow
18 through the annular opening within the metallic seat.

19 [0024] The use of Belleville springs to provide the closing force permits a much more
20 compact valve actuator than the use of coil springs.

21 [0025] In the drive section of the valve which is not wetted by fluids, metal-to-metal
22 bonding may be advantageously accomplished using high-strength adhesives, which do not
23 require subjecting valve mechanicals to the increased temperatures and pressures involved
24 in performing the diffusion bonding used in the wetted section, and which provide a simpler,
25 lower cost, albeit less corrosion / erosion resistant, alternative to diffusion bonding.

26 [0026] The chemical or electrochemical etching and diffusion bonding techniques
27 described above with reference to the manufacture of the wetted section of an on/off valve

1 may be used in the preparation of an entire integrated fluid delivery network architecture for
2 use in corrosive environments, such as those in semiconductor processing. The integrated
3 fluid delivery network architecture includes an assembly employing at least one gas
4 distribution channel, where the assembly comprises a structure which employs a plurality
5 (*i.e.*, at least two) of metal layers which have been diffusion bonded together. The metal
6 layers are typically selected from the group consisting of stainless steel (typically, 400 series
7 stainless steel), HASTELLOY® (typically, HASTELLOY® C-22), ELGILOY®, and
8 combinations thereof. Each of the metal layers typically has a thickness within the range of
9 about 0.0005 inch to about 0.06 inch; more typically, about 0.002 inch to about 0.05 inch;
10 most typically, about 0.025 inch.

11 [0027] A metal layer typically includes a series of through-holes, so that, when the layers
12 are stacked in a particular manner, an aligned combination of the through-holes provides
13 specific desired internal shapes within the stack. The internal shapes include channels or
14 other functional device structures. The through-holes are typically round or oblong in shape,
15 so that there are no sharp corners which can wear and produce particulates during operation
16 of the fluid delivery system. The metal layers are advantageously etched using chemical
17 etching, electrochemical etching, or a combination thereof, to provide the through-holes prior
18 to a diffusion bonding process in which the layers are bonded together to become a functional
19 fluid handling network architecture. The use of chemical, and advantageously,
20 electrochemical etching tends to provide a smoother surface on a through-hole, which aids
21 in reduction of sources of particulate contamination from the fluid handling network
22 architecture. In some instances, depending on the surface condition of the metal layer prior
23 to through-hole etching, the chemical or electrochemical etching process also reduces the
24 roughness of the surfaces which are to be bonded during the diffusion bonding process,
25 enabling better diffusion bonding.

26 [0028] Various component devices, such as laminar flow devices, mass flow controllers
27 or flow sensing devices, flow restrictors, on/off valves, check valves, filters, pressure

1 regulators, and pressure sensors (for example and not by way of limitation), may be
2 incorporated at least in part into the layered structures described above. In some instances
3 a portion of a component device may be surface mounted on the fluid handling network
4 architecture, when it is not practical to include elements of the device in the multilayered
5 structure.

6 [0029] It is advantageous to integrate various component devices into a multi-layered,
7 structure by incorporating at least a portion of the component device within the stack of metal
8 layers prior to bonding. Components that are well suited for incorporation into a diffusion
9 bonded multi-layered structure include filters, pressure sensors, and valves, by way of
10 example and not by way of limitation.

11 [0030] One embodiment of a gas distribution assembly which makes use of multi-layered,
12 diffusion bonded elements is fabricated by a method which includes the following steps:
13 providing a plurality of metal layers; etching at least one feature in more than one of the metal
14 layers (where in some instances not all of the layers need be etched); aligning the plurality
15 of metal layers; and diffusion bonding the plurality of metal layers. Typically the etching is
16 electrochemical etching which provides advantages in terms of surface finish of the etched
17 metal layer.

18 [0031] With respect to the diffusion bonding of corrosion-resistant metal layers, when
19 each of the metal layers is a 400 series stainless steel, or a majority of the metal layers are 400
20 series stainless steel in combination with layers of material which bond at a lower diffusion
21 bonding temperature, diffusion bonding is typically performed at a temperature within the
22 range of about 1000°C to about 1300°C, at a pressure within the range of about 3000 psi to
23 about 5000 psi, for a time period within the range of about 3 hours to about 6 hours. When
24 each of the metal layers is HASTELLOY® C-22, or a majority of the metal layers are
25 HASTELLOY® C-22 in combination with layers of material which bond at a lower diffusion
26 bonding temperature, diffusion bonding is typically performed at a temperature within the
27 range of about 1000°C to about 1300°C, at a pressure within the range of about 8000 psi to

1 about 10,000 psi, for a time period within the range of about 3 hours to about 6 hours. When
2 a combination of 400 series stainless steel layers and HASTELLOY® C-22 layers are
3 diffusion bonded, diffusion bonding is performed at a temperature within the range of about
4 1000°C to about 1300°C, at a pressure within the range of about 4000 psi to about 10,000 psi,
5 for a time period within the range of about 3 hours to about 6 hours. When a combination
6 of 400 series stainless steel layers and ELGILOY® layers are diffusion bonded, diffusion
7 bonding is performed at a temperature within the range of about 1000°C to about 1300°C, at
8 a pressure within the range of about 4000 psi to about 10,000 psi, for a time period within the
9 range of about 3 hours to about 6 hours.

10 [0032] It is also possible to attach a semiconductor processing chamber component to a
11 semiconductor processing chamber using a diffusion bonding process. The semiconductor
12 processing chamber component may be a gas distribution network architecture, or may be a
13 component device selected from the group consisting of manually operated valves, automatic
14 valves, pressure and temperature sensors, flow controllers, filters, pressure regulators, check
15 valves, metering valves, needle valves, and purifiers, for example, and not by way of
16 limitation. The semiconductor processing chamber to which the component is bonded is
17 typically an etch chamber, a chemical vapor deposition (CVD) chamber, or a physical vapor
18 deposition (PVD) chamber, by way of example and not by way of limitation. The particular
19 diffusion bonding process which is used will depend on the materials of construction of the
20 chamber and the chamber component as well as the shape of and accessibility of the surface
21 areas to be bonded.

22 [0033] Also disclosed herein is a method of increasing the etchability of metals which
23 have a microstructure which is resistant to chemical etching (such as HASTELLOY C-22).
24 This is accomplished by temporarily removing the microstructure which provides corrosion
25 resistance to the metal. The microstructure is removed from the metal by heating the metal
26 to a temperature within the range of about 1800°F to about 2000°F for a period of at least a
27 few minutes. The heat-treated metal can be more easily chemically etched than prior to heat

1 treatment. Following chemical etching, the microstructure must be returned to the metal in
2 order for the metal to regain its original corrosion resistance. This is accomplished by heating
3 the metal to a temperature greater than about 2100°F for at least about 30 minutes, followed
4 by rapid cooling of the metal to a temperature of less than about 300°F, within a time period
5 of about 5 minutes. The second heat treatment step can be performed concurrently with
6 diffusion bonding of two or more layers of the metal. The above method is particularly useful
7 for treatment of corrosion-resistant metal alloys which contain between about 43 to about 71
8 weight % nickel, and between about 1 to about 30 weight % chromium, by way of example
9 and not by way of limitation.

10
11 [0034] **BRIEF DESCRIPTION OF THE DRAWINGS**

12 [0035] Figure 1 is a schematic diagram of a cross-sectional view of one embodiment of
13 the inventive on/off valve.

14 [0036] Figure 2 is a schematic diagram of a three-dimensional side view of the
15 embodiment on/off valve 100 shown in Figure 1.

16 [0037] Figure 3A is a schematic diagram of a cross-sectional view of an embodiment of
17 an on/off valve 300 which was fabricated using diffusion bonding.

18 [0038] Figure 3B is a schematic 3/4, three-dimensional view of the valve shown in Figure
19 3A.

20 [0039] Figure 3C is the schematic view Figure 3 B valve, which also shows a temporary
21 rigid, but dissolvable support 363 which is used to hold seat 314 away from diaphragm 302
22 and underlying layer 348 during diffusion bonding of lower section 303 of the on/off valve
23 300.

1 [0040] Figure 4A is an enlarged view of one embodiment of a ring seal, which can be
2 used as a metallic valve seat in an embodiment of a control valve of the present invention.

3 [0041] Figure 4B is a side view of the ring seal shown in Figure 4A.

4 [0042] Figure 5A is a top view of a series of differently patterned, chemically or
5 electrochemically etched metal layers (510, 520, 530, 540, and 550) of the kind which can
6 be diffusion bonded to form a fluid handling structure.

7 [0043] Figure 5B is a three dimensional expanded view of an assembly of the patterned
8 metal layers shown in Figure 5A, but rotated by 180 degrees. Metal layer 530 was repeated
9 five times to produce the proper dimensions of a shape within the nine-layer structure.

10 [0044] Figure 6A is a schematic of a side view of a gas distribution network architecture
11 assembly 600 which includes a number of diffusion-bonded sub-units 610 (similar to
12 structure 500 shown in Figure 5B), in addition to various component devices 620, some of
13 which are more integrated into the underlying substrate 605 than others.

14 [0045] Figure 6B is a three-dimensional, break-apart view of a gas distribution network
15 architecture assembly similar to that shown in Figure 6A, with a high degree of integration
16 of various component devices into the underlying substrate.

17 [0046] Figure 7A is a schematic three-dimensional schematic diagram of an integratable
18 multi-layered pressure sensor 700 of the kind which can be fully integrated into a multi-
19 layered fluid handling network architecture..

20 [0047] Figure 7B is a schematic diagram of a side view of side 702 of the pressure sensor

1 700 shown in Figure 7A, with a cross-sectioning marker A – A illustrated thereon.

2 [0048] Figure 7C is a schematic diagram of a side view of side 704 of the pressure sensor
3 700 shown in Figure 7A, with a cross-sectioning marker B – B illustrated thereon.

4 [0049] Figure 7D is a schematic diagram of the cross-sectional view A – A of the pressure
5 sensor 700 shown in Figure 7B.

6 [0050] Figure 7E is a schematic diagram of the cross-sectional view B – B of the pressure
7 sensor 700 shown in Figure 7C.

8 [0051] Figure 7F is an exploded three dimensional view of the pressure sensor 700 shown
9 in Figure 7A, illustrating the individual component layers which make up the fully
10 integratable pressure sensor.

11 [0052] Figure 7G is an enlarged view of underside 742 of the ceramic disk 724,
12 illustrating the center electrode 744 and the exterior electrode 746.
13

14 [0053] Figure 8A is a schematic break-away view of a starting structure 800 for forming
15 a layered structure 830 including a fully integratable in-line filter.

16 [0054] Figure 8B is a schematic showing a top view of the layered structure 830 produced
17 from starting structure 800, with cross-sectional marker A – A illustrated thereon.

18 [0055] Figure 8C is a schematic showing the cross-sectional view A – A of layered
19 structure 830 including a fully integrated particulates in-line filter 850.

1 [0056] Figure 8D is a schematic showing a more three-dimensional three quarter view of
2 layered structure 830 and illustrating the inlet 832 and outlet 834 for in-line filter 850.

3 [0057] Figure 9A is a top view of an integrated fluid delivery system 900 which includes
4 a number of gas distribution assemblies 910 (gas sticks) of the kind shown in Figure 6B, with
5 the gas sticks attached to manifold systems 930 and 940.

6 [0058] Figure 9B is a three-dimensional view of the integrated fluid delivery system 900
7 shown in Figure 9A.

8 [0059] Figure 10 is a process flow diagram for a process for passivation of a stainless steel
9 surface to render it more corrosion resistant.

10 [0060] **DETAILED DESCRIPTION OF THE INVENTION**

11 [0061] As a preface to the detailed description, it should be noted that, as used in this
12 specification and the appended claims, the singular forms “a”, “an”, and “the” include plural
13 referents, unless the context clearly dictates otherwise. When the term metal or metallic is
14 used, it is understood that this includes metal alloys. Other terms important to an
15 understanding of the invention are defined in context throughout the application.

16 [0062] For purposes of illustration, the first embodiment of a layered structure concept
17 will be described with respect to the design of compact fluid on/off valve where a portion of
18 the compact fluid on/off valve is integrated into a fluid handling network architecture.
19 Figures 1 and 2 illustrate one embodiment of a valve 100 which incorporates a number of
20 inventive features. In Figures 1 and 2, all of the valve parts which contact (are wetted by)
21 fluid flowing through the valve are metallic. In particular, parts 102, 103, and 114 are wetted
22 parts. Typically, the metallic material is highly corrosion-resistant. Valve 100 includes a
23 metal diaphragm 102 separating the wetted section 104 of the valve 100 from the drive

1 section 106 of the valve 100. The metal diaphragm 102 provides a seal against metal valve
2 seat 114 when the valve 100 is in its normally-closed position. Once a fluid, illustrated by
3 arrow 107, has entered through entrance port 108, lower surface 115 of diaphragm 102 is in
4 contact with the fluid, both when valve 100 is open or closed. It is advantageous to use a
5 corrosion-resistant material on surface 115 of diaphragm 102. The diaphragm 102, in
6 addition to being highly corrosion-resistant, must also have good flexure characteristics if it
7 is to survive long periods of numerous open-close cycles. To ensure that there will be no
8 leakage into the environment, leakage of process gas from the wetted section 104 of the valve
9 100 into the drive section 106 of the valve 100 must be 1×10^{-9} cc/sec or less (SEMI F1
10 standard) for at least 15 seconds, at a pressure difference of 1 atm He across the valve sealing
11 interface 103S. With respect to chamber 131, which is the low pressure, atmospheric side
12 of the diaphragm 102, this chamber is typically vented to atmosphere by a diaphragm top side
13 vent 138, so that pressure cannot build up.

14 [0063] The metal diaphragm 102 can advantageously be fabricated of a nickel-cobalt
15 alloy, such as ELGILOY®, SPRON™ 510 (available from Seiko Electron), SPRON™ 100,
16 HASTELLOY®, or INCONEL®. The diaphragm can be either a single thickness or a
17 laminate. In many cases, the diaphragm will be multi-layered, with two to three diaphragms
18 layered (not necessarily bonded) together. Multi-layered diaphragms provide a better seal and
19 add springiness. An individual diaphragm will typically have a thickness within the range
20 of about 0.001 to about 0.007 inch (0.1 mil to 7 mil). The individual diaphragms within a
21 multi-layered diaphragm will typically (but not necessarily) be of the same material.
22 Alternatively, instead of using a multi-layered diaphragm, an individual diaphragm that has
23 been machined to be of variable thickness may be used.

24 [0064] The diaphragm 102 is held in place by its edge which is adhered to a surface 103s
25 of wetted body section 103 so that diaphragm 102 is retained between the lower wetted body
26 section 103 and the non-wetted drive body section 117. The joint between the diaphragm 102
27 and the wetted body section 103 is typically a diffusion bonded joint. Alternatively, the joint
28 may be bonded using laser welding. However, diffusion bonding typically provides a

1 stronger and more reliable bond.

2 [0065] The lower body section 103 of valve 100 includes surfaces 105 which are wetted
3 by fluids passing through the valve 100. Typically, it is advantageous to form lower body
4 section 103 from a corrosion-resistant metal or metal alloy, such as 400 series stainless steel,
5 HASTELLOY C-22® (a registered trademark of Haynes International, Inc. of Kokomo,
6 Indiana), INCONEL® (a registered trademark of the Special Materials Metal Corp., a group
7 of companies, having offices in New Hartford, New York), and ELGILOY ® (a registered
8 trademark of Elgiloy Specialty Metals, Elgin, Illinois). These same materials may be used
9 to fabricate diaphragm 102. As previously mentioned, diaphragm 102 must be somewhat
10 flexible, the thickness of the diaphragm typically ranges from about 0.025 mm to about 0.18
11 mm; and, in the embodiments described herein, the diaphragm was about 0.1 mm thick.

12 [0066] The drive section 106 of valve 100 may be fabricated of these same materials, or
13 may be fabricated from less expensive materials which are not as corrosion-resistant, since
14 the surfaces of components of drive section 106 are not wetted by fluids which flow through
15 the valve 100. By way of example, housing 137 and sliding cylinder 121 may be fabricated
16 from aluminum and stainless steel. However, the cone disk springs 122 are typically made
17 from high carbon steel, such as ASTM A510.

18 [0067] The various parts of the valve will now be described, with respect to Figures 1 and
19 2, in terms of their function during operation of the valve.

20 [0068] The process fluid (or fluids), indicated by arrows 107, enter through an entrance
21 port 108 (ports 108) present within lower body section 103 of the valve 100. In doing so, the
22 process fluid contacts surfaces 105 of lower body section 103 within wetted section 104.
23 When the valve 100 is in an open or partially-open position, permitting fluid to flow through
24 the valve 100, exiting fluid, illustrated by arrow 109, will flow out of exit port 110, over inner
25 lip 112 of annular metallic valve seat 114.

26 [0069] When the valve 100 is in the closed position, the fluid flow is interrupted by a
27 section of the diaphragm 102 being pressed tightly against an upper surface 119 of the metal
28 valve seat 114 by lower horizontal member 116 of sliding cylinder 121. The lower surface

123 of lower horizontal member 116 is convex-shaped, so that it can act as a backing disk behind diaphragm 102. Lower horizontal member 116 is considered to be part of drive section 106, since lower horizontal member 116 is not wetted by fluids passing through valve 100. The diaphragm 102 may be free-moving, or may be bonded to the convex surface 123 of lower horizontal member 116, for example, by e-beam welding, or direct bonding, or other bonding techniques known in the art. The convex surface 123 of lower horizontal member 116 which contacts diaphragm 102 is typically made of a material which has a hardness less than that of the diaphragm material. If the diaphragm 102 is made of a nickel-cobalt alloy (for example, and not by way of limitation, ELGILOY®, SPRON™ 510, SPRON™ 100, HASTELLOY®, or INCONEL®), the convex surface 123 may be made of 304 stainless steel, by way of example, and not by way of limitation.

[0070] The metallic valve seat 114 is formed as part of, or upon, the inner lip 112 of the exit port 110. Depending upon its design, the metal valve seat 114 may be advantageously fabricated from metal or a metal alloy, such as, for example and not by way of limitation, stainless steel, ELGILOY®, SPRON™ 100, or SPRON™ 510. Most typically, the metallic valve seat 114 is fabricated from 400 series stainless steel. Metallic valve seat 114 may be, for example, any of the commercially available C-seals, such as, by way of example and not by way of limitation, the MICROSEAL® ring seal available from Microflex Technologies LLC., which is shown in Figure 4 and described in detail in U.S. Patent No. 6,357,760, issued March 19, 2002, to Doyle. Because of its particular geometry, the MICROSEAL® ring seal typically has a better elastic range than many other commercially available seals, providing a flexibility which is desirable for use in a valve seat of the present invention.

[0071] With reference to Figure 4A, the ring seal shown, which is useful as a valve seat in the present inventive valve, has an annular shaped body element 3, with an axial aligned center hole 4 for permitting the passage of gases or fluids therethrough. The seal includes a radial inner surface 5, a radial outer surface 6, a first axial surface 11, and a second axial surface 17, as shown in Figure 4B. Each of these surfaces may take any number of configurations.

1 [0072] The ring seal shown in Figures 4A and 4B further includes a plurality of bores 25
2 which project inwardly from the seal's radial outer surface 6 toward the seal's center hole 4.
3 The non-axially aligned sidewalls 27 which form bores 25 are believed to be particularly
4 suited where the application for the seal requires significant deformation for a particular load,
5 and this kind of ring seal performs very well in the valve of the present invention. Other ring-
6 shaped seals may also be used, and it is not intended that the valve design be limited to one
7 employing the particular ring seal described above.

8 [0073] In addition to its high corrosion resistance, the metallic valve seat 114 has the
9 property of being a dynamic seat. The seat is designed, and its material or materials of
10 construction selected, to deform sufficiently to seal off the exit port 110 to the required level
11 of cross-seat leakage, when pressed upon by the diaphragm 102. When valve 100 is in the
12 normally-closed position, it is required that the cross-seat leakage level is no more than about
13 1×10^{-9} cc/sec or less (SEMI F1 standard) for at least 15 seconds, at a pressure difference of
14 1 atm He across the valve diaphragm / seat interface. Preferably, the metallic seat 114
15 deformation remains in the elastic regime, so that the metallic seat 114 recovers each time
16 the valve 100 is closed and reopened, rather than being permanently deformed by the valve's
17 closure. It is anticipated that this feature will greatly increase the valve's reliability and
18 useful lifetime.

19 [0074] Bonding of the valve 100 non-wetted drive body section 117 to the lower wetted
20 body section 103, and bonding of a metallic valve seat 114 to an inner lip 112 of an annular
21 metallic valve seat 114, may be advantageously accomplished by diffusion bonding.
22 Diffusion bonding is a direct bonding process which provides smooth, strong bonds that do
23 not absorb or release process fluids, and do not contribute impurities to the process fluids, as
24 a welded joint might do. A process for diffusion bonding two metallic components involves
25 finishing their mating faces to a very clean, smooth, and flat surface finish, then applying
26 pressure and heating the components until the atoms of the respective surfaces interdiffuse,
27 forming an interlocked layer, without liquefying either of the surfaces or introducing any
28 voids, pits, or inclusions. Another process such as laser welding may be used when a two-

1 step diffusion bonding process is used to fabricate body section 103.

2 [0075] In order for diffusion bonding to be effective, the metal surfaces that are to be
3 bonded must have a surface roughness within the range of about 0.5 Ra to about 30 Ra prior
4 to diffusion bonding. Typically, the metal surfaces have a surface roughness within the range
5 of about 0.5 Ra to about 10 Ra; more typically, within the range of about 1.5 Ra to about 5
6 Ra. We have found that diffusion bonding works quite well when the metal surfaces have
7 a surface roughness within the range of about 1.5 Ra to about 3.0 Ra.

8 [0076] In many cases, the metal surfaces will need to be pretreated by chemical etching,
9 or a combination of mechanical planarization and chemical etching, to have the desired
10 surface roughness prior to diffusion bonding. For example, stainless steel can be chemically
11 etched using ferric chloride according to standard methodology known in the art. A process
12 for electrochemical etching of difficult to etch materials such as HASTELLOY is described
13 in U.S. Patent No. 6,221,235, issued April 24, 2001, to Gebhart.

14 [0077] Certain materials may require mechanical planarization to smooth down the
15 surface prior to the performance of a chemical etching process to obtain a surface roughness
16 within the desired range. Mechanical planarization of metal surfaces can be performed
17 according to techniques known in the art.

18 [0078] In some instances, the metal surfaces may be manufactured with the desired surface
19 roughness, and may need no chemical or mechanical pretreatment prior to diffusion bonding.
20 For example, the ASTM standard for surface roughness for stainless steel sheets (as rolled)
21 is 0.5 Ra to 4.0 Ra (ASTM 480 BA).

22 [0079] Once the metal surfaces to be bonded have been polished to the desired surface
23 roughness, diffusion bonding is performed. The particular pressure applied during the
24 diffusion bonding process, and the particular temperature at which the diffusion bonding
25 process is performed, will depend on the materials being bonded. Some typical conditions
26 for forming a successful diffusion bond between similar or dissimilar metal surfaces of the
27 sort that have been discussed above are shown in Table One, below:

[0080] Table One. Conditions for Diffusion Bonding of Various Metals

Materials being Bonded	Temperature	Pressure	Contact Time
316L Stainless Steel to 316L Stainless	1000 - 1300 °C	3000 - 5000 psi	3 - 6 hours
410 Stainless Steel to 410 Stainless	1000 - 1300 °C	3000 - 5000 psi	3 - 6 hours
HASTELLOY® C-22 to HASTELLOY C-23	1000 - 1300 °C	8000 - 10,000 psi	3 - 6 hours
400 series Stainless Steel to HASTELLOY® C22	1000 - 1300 °C	4000 - 10,000 psi	3 - 6 hours
400 series Stainless Steel to ELGILOY®	1000 - 1300 °C	4000 - 10,000 psi	3 - 6 hours

[0081] Pressures and temperatures in the ranges shown above would certainly prove deleterious to some materials present in the drive section 106 of the valve, and this must be taken into consideration in the planning of assembly for valve 300 of the kind shown in Figures 3A and 3B. For example, in the manufacture of valve 300, a high temperature diffusion bonding process can be run first, to bond layers 338 - 356 shown in Figures 3A and 3B (layers 358, 360, and 362 were adhesive bonded). Since the layers such as 340, and 342, for example, are typically about 0.025 inches (about 0.0635 mm) thick, patterns can be wet chemically or electrochemically etched using techniques known in the art, to produce patterned sheet materials for diffusion bonding into valve structures. The chemical or electrochemical etching provides smooth surfaces in the patterned areas, which smooth surfaces appear on the internal wetted valve structure surfaces. This reduces the possibility of contamination of fluids flowing through the valve. Use of a 0.025 inch thick metal layer is advantageous because this thickness of metal layer is readily available from suppliers; provides reasonable pattern etching times; and is of adequate thickness to accommodate a C-seal in a counterbore of the type used for surface mount of component devices. The

1 assembled, bonded structure may employ complex shapes without the need for complicated
2 and costly machining. Other components (such as the sliding cylinder 321, sliding seals 313
3 and 320, and/or metallic seat 314) may be adhered/bonded afterward. The piston portion 316
4 of sliding cylinder 321 can be lifted out prior to diffusion bonding, which is carried out before
5 assembly.

6 [0082] Metallic seat 314 can be bonded to layer 348 by two different techniques.
7 With reference to Figure 3B, in the first technique, a first assembly of layers including layers
8 338, 340, 342, 344, 346, and 348 may be diffusion bonded. Then, prior to assembly with the
9 other layers in the layered substrate 303, metallic seat 314 may be bonded to layer 348 either
10 by laser welding or by diffusion bonding. A second assembly of layers, 350, 302, 354, and
11 356 may be diffusion bonded together. Then, the first assembly of layers may be diffusion
12 bonded to the second assembly of layers. This technique makes it possible to diffusion bond
13 the layered substrate 303 while avoiding placing undue pressure on metallic seat 314. In a
14 second technique for bonding metallic seat 314, with reference to Figure 3C, a rigid, but
15 dissolvable support 363 may be used to enable the diffusion bonding in a single step. The
16 dissolvable support 363 includes a central domed section 367, which holds diaphragm 302
17 away from the upper surface 365 of support 363 during the diffusion bonding process. In
18 addition, rigid dissolvable support 363 includes a cup-shaped lip 369 which underlies the
19 lower surface of metallic seat 314. After bonding of layered substrate 303, the rigid
20 dissolvable support 363 is dissolved in an appropriate solution. The rigid dissolvable support
21 must be capable of withstanding the temperature experienced by the substrate during
22 diffusion bonding and must be capable of dissolution without leaving behind particulate
23 residue which affects the ability of the valve to perform reliably. The interior space beneath
24 diaphragm 302 may optionally be cleaned with a cleaning solution to remove any residues
25 from the upper surface of layer 348 which remain after the step in which the dissolvable
26 support 363 is removed. The interior open surfaces of layered substrate 303 may be blown
27 dry using nitrogen or another inert gas, and may be dried using heat and vacuum if desired,
28 depending on the dissolving solution and/or cleaning solution used. The metallic seat 314

1 is then bonded to layer 348 through port 310.

2 [0083] Diffusion bonding techniques (such as described above) can be used in the
3 manufacture of other gas handling elements, such as flow rate controllers, filters, and sensors,
4 for example and not by way of limitation. This will be illustrated in detail with respect to the
5 layered substrate technology described subsequently.

6 [0084] In the valve's drive section 306, above the diaphragm which isolates the wetted
7 section 304, the sliding cylinder 321 moves in and out, such that the convex surface 323 of
8 lower horizontal member 316 of sliding cylinder 321 presses against diaphragm 302 to
9 restrict the flow of fluids within wetted section 304. Chamber 331, which is the low pressure,
10 atmospheric side of the diaphragm 302, this chamber is typically vented to atmosphere by a
11 diaphragm top side vent 364, so that pressure cannot build up. The motion of sliding cylinder
12 321 is achieved by balancing the force applied to upper horizontal member 318 (which is tied
13 by vertical member 334 to lower horizontal member 316) by a spring 322 positioned within
14 housing 337, and the force applied to lower horizontal member 316 by a fluid present in a
15 pneumatic chamber 339. The sliding cylinder 321 has a gas-tight sliding seal (typically an
16 "O - Ring") 320 around the perimeter of upper horizontal member 318, and a gas-tight sliding
17 seal 313 around the perimeter of lower horizontal member 316. Since the sliding seals do not
18 contact fluids passing through valve 300, they need not be metal, and may comprise a
19 polymeric material. The sliding seals (O-rings) 320 and 313 are typically fabricated from an
20 elastomeric material.

21 [0085] The valve 300 is maintained in a normally-closed position by force applied by
22 spring 322 upon upper horizontal member 318 of sliding cylinder 321. When the valve seat
23 314 is metallic, the seating force required for absolute shutoff (a fluid flow of less than 1×10^{-9} cc/sec for at least 15 seconds, at a pressure difference of 1 atm He across the valve) is
24 in the range of 1000 N/cm^2 at the sealing contact surface 319 of valve seat 314. This
25 translates to roughly 200 to 250 Newtons of force for an annular valve seat 314 having an
26 exterior diameter of about 0.70 cm and a total contact surface area of about 0.233 cm^2 .
27
28 Figures 3A and 3B show the spring 322 used to apply force to the upper surface 328 of upper

1 horizontal member 318 as a “Belleville” spring, which may also be referred to as a cone disk
2 spring. The application of Belleville springs typically takes the shape of a series of coned
3 disks stacked atop one another, concave side to convex side, as illustrated in Figures 3A and
4 3B.

5 [0086] Figures 3A and 3B show 8 cone disk springs, and the forces referred to herein
6 are with respect to the 8 cone disk springs, but other numbers of such springs may be used,
7 depending on the application. A Belleville spring provides the closing force required within
8 a much smaller vertical distance “d ” than would be required by a coil spring. This permits
9 a much shorter valve actuator than can be achieved using coil springs. The metal-seated
10 valve shown in Figure 1 using coil springs to provide tight shutoff would typically require
11 a “d” ranging from about 2.0 cm to about 3.0 cm, while a Belleville spring combination
12 would typically require a “d” ranging from about 0.5 cm to about 2.0 cm.

13 [0087] The valve 300 is opened by pneumatic force, which is applied by admitting
14 pressurizing gas (not shown) into the pneumatic chamber 309 via port 324. Since the
15 movable surface area 330 of upper horizontal member 318 of sliding cylinder 321 is much
16 larger than the movable surface area 311 of lower horizontal member 316, the pressurizing
17 gas provides an upward motion against the operation of spring 322. The pressurizing gas
18 (not shown) is admitted through one or more ports 324 from an external compressed air gas
19 supply of 40 - 75 psig. The pneumatic pressure behind upper horizontal member 318 then
20 overcomes the countervailing spring 322 force, urging the sliding cylinder 321 upward, in
21 proportion to the amount of pressure applied via the pressuring gas. As sliding cylinder 321
22 moves upward, lower horizontal member 316 moves upward, relieving pressure upon
23 diaphragm 302, which moves away from the metallic valve seat 314, opening the valve by
24 an amount in proportion to the pressure applied via the pressurizing gas. For a valve of the
25 kind shown in Figures 3A and 3B, where the movable surface area 330 is about 1.5 cm^2 , the
26 movable surface area 311 is about 0.40 cm^2 , and the downward force applied by spring 322
27 to surface 328 of upper horizontal member 318 to crack the valve open is about 220 N. The
28 pressurizing gas pressure applied will be in the range of about 1,480 kPa for an 8 spring valve

1 to open the valve and will be in the range of about 2,220 kPa to provide full flow. In the
2 event that the pressurizing gas leaks past the sliding seals 320, the gas can vent out through
3 opening(s) 332 in housing 337.

4 [0088] In the drive section 306 of the valve 300, required metal-to-metal bonding may be
5 advantageously accomplished using high-strength adhesives. While adhesives typically do
6 not provide quite as strong or reliable a bond as diffusion bonding, they do not require
7 subjecting the valve mechanicals present in the drive section 306 to the much higher
8 temperatures and pressures involved in performing the diffusion bonding used in the wetted
9 section 304. Adhesives are also much cheaper and simpler to use than diffusion bonding.
10 Adhesives used in this application typically provide a shear strength of not less than 3,000
11 psi and a shear modulus of not less than 45,000 psi at 24 °C. One example of an adhesive
12 which has been satisfactory for this application is SCOTCH-WELD™ epoxy adhesive 2216
13 (B/A grey), which may be applied and bonding processed in the manner recommended by the
14 manufacture, with respect to the particular materials being bonded. This particular adhesive
15 acts as a sealant as well as an adhesive. One skilled in the art will be able to find other
16 adhesive/sealant compositions which can be used in this application which typically requires
17 functionality at room temperature up to about 40 °C. For higher temperature applications,
18 an adhesive/sealant having higher temperature functionality could be selected.

19 [0089] Due to the high cost of corrosion-resistant materials of the kind used in the
20 manufacture of semiconductor processing equipment, as well as the high cost of space in the
21 clean room environment of semiconductor fabrication facilities, there is a drive to reduce the
22 size of the fluid handling devices used. In particular, recent emphasis has been placed on
23 reducing the size of the fluid handling system in general, equipment which has historically
24 occupied a substantial portion of the overall processing floor space.

25 [0090] Disclosed herein is a space conserving, integratable fluid handling network
26 architecture for use in the chemical processing industry, where space is a concern, such as
27 in semiconductor processing equipment. The fluid delivery network can be manufactured
28 using the chemical etching and diffusion bonding techniques described with respect to the

1 lower section 303 of the diaphragm valve described above.

2 [0091] In some instances, where the metals to be diffusion bonded are particularly
3 difficult to etch, it may be necessary to use electrochemical etching to drive the etching
4 process.

5 [0092] The integrated fluid handling network architecture includes a gas distribution
6 assembly which comprises a structure including a plurality (*i.e.*, at least two) of metal layers
7 which have been diffusion bonded together. The number of metal layers in a typical gas
8 distribution assembly generally ranges from about 3 to about 15. Each of the metal layers
9 typically has a thickness within the range of about 0.0005 inch to about 0.06 inch; more
10 typically, about 0.003 inch to about 0.05 inch; most typically, about 0.025 inch. The layers
11 may have the same thickness, or vary in thickness, depending on the desired final structure.

12 [0093] The metal layers may be selected from a number of different corrosion-resistant
13 materials. For purposes of illustration herein, the metal layers are typically selected from the
14 group consisting of stainless steel, HASTELLOY®, and ELGILOY®, and combinations
15 thereof. Specifications for 400 series stainless steel, HASTELLOY® C22, and ELGILOY®
16 are presented in Table Two, below.

[0094] Table Two. Specifications for 316L and 400 series Stainless Steel.
HASTELLOY® C-22 and ELGILOY®

Specification	316L Series Stainless Steel	400 Series Stainless Steel (Type 410)	HASTELLOY® C-22	ELGILOY®
Composition (% by wt. Maximum)	61.8 Fe, 18 Cr, 14 Ni, 3 Mo, 2 Mn, 1 Si, 0.1N, 0.045 P, 0.03 C, 0.03 S	Fe balance, 12 Cr, 1 Mn, 1 Si, 0.50 Ni, 0.15 C, 0.04 P, 0.03 S	56 Ni, 22 Cr, 13 Mo, 3 W, 3 Fe, 2.5 Co, 0.50 Mn, 0.35 V, 0.08 Si, 0.010 C	41 Co, 21 Cr, 16 Ni, 11.4 Fe, 8 Mo, 2.5 Mn, 0.15 C
Avg. Surface Roughness (Ra)	0.5 - 4.0	5 - 30	5 - 30	5 - 30
Hardness, Rockwell (R _C) Sheet Plate	25	43	15 15	45 60
Melting Temperature (°C)	2500 - 2550	1482 - 1532	1357 - 1399	1427 - 1457
Mean Coefficient of Thermal Expansion (m/m-°K) -18 to 315 °C 20 to 600 °C 24 to 649°C 0 to 500°C	0.5 x 10 ⁻⁶	11.6 x 10 ⁻⁶	14.6 x 10 ⁻⁶	15.2 x 10 ⁻⁶
Thermal Conductivity (W/m ² -°K) 27°C 48°C 100°C	0.63	24.9	10.1	12.5
Specific Heat @ 52°C (J/kg-°K)	500	459	414	430

1 [0095] The metal layers are patterned to contain a series of through-holes, which are
2 typically round or oblong in shape, so that there are no sharp corners which can wear and
3 produce particulates during operation of the fluid delivery system. The metal layers are
4 advantageously etched using chemical etching, electrochemical etching, or a combination
5 thereof, to provide the pattern of through-holes in prior to a diffusion bonding process in
6 which the layers are melded together to become a functional fluid handling device. The use
7 of chemical, and in particular electrochemical etching tends to provide a smoother surface
8 on the through-hole, which aids in reduction of sources of particulate contamination from the
9 fluid handling system. In some instances, depending on the surface condition of the metal
10 layer prior to through-hole etching, the electrochemical etching process also reduces the
11 roughness of the surfaces which are to be bonded during the diffusion bonding process,
12 enabling lower roughness diffusion bonding.

13 [0096] Chemical or electrochemical etching of the metal layers to produce a pattern of
14 openings in the layers is typically performed according to methods known in the art, which
15 will depend on the particular metal to be etched. Electrochemical machining is a technique
16 that has been in use for metal polishing and removal for several decades. Use of the driving
17 force of an electrochemical process to enable the etching of difficult to etch materials is well
18 known in the art. For example, a paper was presented by D.M. Allen, and P.J. Gillbanks
19 entitled: "The Photochemical Machining of Some Difficult - To - Etch Metals" at NEPCON
20 WEST: Packing Production Testing, February 25 - 27, 1986, which related to this subject
21 matter. At the same conference, T.A. Allen, Sandia National Laboratories, presented work
22 on the pulsating of an electrochemical cell to perform chemical machining of molybdenum
23 through a photoresist mask.

24 [0097] Stainless steel can be chemically etched using ferric chloride according to standard
25 methodology known in the art. A process for electrochemical etching of steel is described
26 in U.S. Patent No. 6,221,235, issued April 24, 2001, to Gebhart. Although the Gebhart
27 patent pertains to complete bulk dissolution of a sacrificial core, the application of a pulsed

1 current of the kind described by Gebhart is also applicable to the etching of metal through
2 a mask, as described by Datta in IBM J. Res. Dev. Vol. 42, No. 5, Sept. 98, pp. 655 - 669.
3 The Datta disclosure combines the mass-manufacturability of an etch process which employs
4 a patterned photoresist with pulsed electrochemical dissolution of the kind described in the
5 Gebhart patent. As previously mentioned, the electrochemical machining technique has been
6 used for molybdenum; and, the process can be applied to etching of HASTELLOY® and
7 ELGILOY®.

8 [0098] It is possible to make highly corrosion-resistant metals, such as HASTELLOY®
9 and ELGILOY® easier to pattern etch by chemical or electrochemical techniques by
10 temporarily removing the microstructure which provides surface corrosion resistance. This
11 may be accomplished by heating the metal to a temperature within the range of about 1800°F
12 to about 2000°F; more typically, within the range of about 1825°F to about 1975°F; most
13 typically, about 1900°F. Heat treatment is performed in an atmosphere of clean nitrogen for
14 a time period within the range of a few minutes minimum. The metal is then cooled over a
15 time period ranging from about 5 minutes to as much as 30 minutes. Chemical or
16 electrochemical etching of the metal is then performed according to methods known in the
17 art and described herein. Use of this method to adjust the microstructure of the corrosion-
18 resistant metal prior to electrochemical etching is expected to improve the etch rate by a
19 factor ranging from 100 to 1,000 times, depending on the particular alloy.

20 [0099] Following the pattern etching of the metal by chemical or electrochemical
21 techniques, the microstructure of the metal must be returned to the metal in order for the
22 metal to regain its original corrosion resistance. This is accomplished by heating the metal
23 to a temperature greater than about 1,135°C (typically, no greater than about 1,200°C) for a
24 few minutes minimum, followed by rapid cooling (quenching) of the metal to a temperature
25 in the range of about 130 °C or less over a time period of about 5 minutes or less. The
26 temperature at which the microstructure is returned to the metal is typically very close to the
27 temperature at which the metal is diffusion bonded, so that the microstructure is typically

1 returned to the metal during the diffusion bonding process. However, following heating of
2 the metal during the diffusion bonding process, the metal must be cooled to a temperature of
3 less than about 135°C (typically, to a temperature within the range of about 80°C to about
4 135°C) within a time period of less than about 5 minutes in order for the microstructure of
5 the metal to be returned. Optionally, the heat treatment / rapid cooling process can be
6 performed as a separate processing step prior to performance of the diffusion bonding
7 process. The above method is particularly useful for treatment of corrosion-resistant metal
8 alloys which contain between about 43 to about 71 weight % nickel, and between about 1 to
9 about 30 weight % chromium, such as the HASTELLOY® series of alloys (available from
10 Haynes International, Inc., Kokomo, IN), which includes HASTELLOY® B-2,
11 HASTELLOY® B-3, HASTELLOY® C-4, HASTELLOY® C-22, HASTELLOY® C-2000,
12 HASTELLOY® C-276, HASTELLOY® G-30, and HASTELLOY® N. [0098] One
13 skilled in the art with minimal experimentation can determine what the heating and quench
14 cycles should be to adjust the microstructure for easy etching and then to return the
15 microstructure to its original corrosion resistant properties after etch using a similar heat and
16 quench cycle.

17 [0100] Although Stainless Steel 410, for example and not by way of limitation, may be
18 able to be cleaned and diffusion bonded without the need to adjust the microstructure of the
19 steel, the hardness of the steel layer underlying the metallic seat 314 shown in Figure 3B
20 needs to be improved after diffusion bonding. Metallic seat 314 cannot provide the proper
21 seal unless the metallic layer 348 underlying the metallic seat 314 exhibits a Vickers hardness
22 of at least 300. The adjustment of the metal microstructure to improve the hardness of the
23 Stainless Steel 410 is achieved by heating the metal to a temperature of at least 980 °C for
24 a time period ranging from about 3 minutes to about 10 minutes, followed by a quenching
25 to a temperature in the range of about 135°C within a period of less than about 5 minutes.

26 [0101] Stainless Steel 316L hardness improvement is more difficult. The 316L Stainless
27 Steel requires surface working for hardening. This may be accomplished by roller burnishing

1 of the surface of layered substrate layer 348 through counter bore 310 after the diffusion
2 bonding.

3 [0102] In addition to adjusting the hardness of a stainless steel layer underlying metallic
4 seat 314, surfaces of the stainless steel which are to be contacted with corrosive fluids may
5 need to be treated to improve resistance to corrosion after the diffusion bonding step.

6 Treatment to improve corrosion resistance may be carried out prior to the roller burnishing
7 of the surface of a stainless steel layer 348 when that layer is 316L Stainless Steel. Treatment
8 of stainless steel layers to improve corrosion resistance will be discussed subsequently herein.

9 [0103] One of the benefits of chemical or electrochemical etching over other methods of
10 machining is that it is possible to make changes in the design of the component easily and
11 at a low cost. It is possible to make either small or large quantities of etched components,
12 and the process becomes more cost effective as the number of components produced
13 increases.

14 [0104] In general, in order for diffusion bonding to be most effective, the metal
15 surfaces that are to be bonded must have an average surface roughness within the range of
16 about 0.1 Ra to about 5 Ra, with a maximum surface roughness not to exceed about 30
17 Ra, prior to diffusion bonding. Typically, the metal surfaces to be bonded have a surface
18 roughness within the range of about 0.5 Ra to about 5 Ra. We have found that diffusion
19 bonding works quite well when the metal surfaces have a surface roughness within the
20 range of about 1.5 Ra to about 3.0 Ra.

21 [0105] As previously mentioned, it is possible to directly purchase some grades of
22 stainless steel which meet surface roughness requirements, and the metal surfaces not will
23 need to be pretreated to have the desired surface roughness prior to diffusion bonding. If
24 the desired surface roughness material is not available, 316L and 400 series stainless
25 steels can be electropolished, using techniques known in the art, to provide the desired
26 surface roughness. Once the desired surface roughness is achieved, the stainless steel
27 layers can be diffusion bonded into the desired layered substrate assembly. After

1 diffusion bonding, it is necessary to treat the stainless steel surfaces which are to be
2 exposed to corrosive fluids to render such surfaces more corrosion resistant. For this
3 reason, it is recommended that the layered substrate layers which are to be exposed to
4 corrosive fluids be fabricated from a corrosion-resistant material such as HASTELLOY®
5 or ELGILOY®. However, for cases where it is considered to use a stainless steel layer in
6 the layered substrate at a location which is exposed to corrosive fluids, the surfaces of the
7 stainless steel layers which will be exposed to corrosive fluids may be passivated after the
8 diffusion bonding step. The passivation step typically tends to bring more of the
9 chromium present in the steel to the surface of the steel. The passivation step involves
10 exposing the stainless steel substrate to a series of steps which are illustrated in Figure 10.

11 [0106] In particular, with reference to Figure 10, a diffusion bonded layered
12 substrate containing stainless steel surfaces to be passivated is treated using the method
13 1800 shown in Figure 10. The stainless steel surfaces are cleaned 1802 with a first
14 detergent or cleaning agent. If any of the surfaces have been machined after diffusion
15 bonding, these surfaces need to be degreased to remove grease, metal filings or
16 cutting/drilling fluids. We have found that a good cleaning agent for this purpose is a
17 solution of potassium hydroxide, about 35 % by volume in deionized water. A solution
18 of the cleaning agent may be sprayed on the surface to be cleaned, to provide good
19 agitation of the surface and then the part may be immersed into a bath (typically
20 ultrasonically agitated) to clean out holes and cavities. A typical immersion bath
21 temperature is about 60 °C and a typical time period for treatment is about 20 minutes.
22 After detergent cleaning, the layered substrate (or other stainless steel part) is
23 rinsed/cleaned 1804 using deionized water, followed by drying 1806 with hot nitrogen gas
24 which is typically at a temperature ranging from about 65°C to about 75°C. Treated
25 surfaces are then inspected for cleanliness using a 10 power or higher magnifying glass
26 and if the surfaces are free from contamination which will affect the ability of the surface
27 to perform its function, the part comprising the stainless steel surface to be treated is sent

1 on for nitric acid passivation 1808. If the surfaces are not free from contamination, steps
2 1802 through 1808 are repeated 1810 until such surfaces are properly cleaned.

3 [0107] The nitric acid passivation process 1812 comprises treating the cleaned stainless
4 steel surface with a solution which is 20 % by volume nitric acid in a deionized water
5 base. The stainless steel parts are contacted with the nitric acid solution for a time period
6 ranging from about 25 minutes to about 30 minutes at a temperature ranging from about
7 45 °C to about 50 °C.

8 [0108] After treatment with the nitric acid solution, the stainless steel surfaces are
9 rinsed 1814 with deionized water, followed by treatment with a second detergent.

10 Although one skilled in the art may select a suitable detergent, we found that
11 ALCONOX® Powdered Precision Cleaner, a trisodium phosphate, dissolved to make a 1
12 % by weight solution in deionized water works well. The stainless steel surfaces were
13 immersed in a circulating bath made up from about 2.5 to 3 teaspoons of the
14 ALCONOX® Powdered Precision Cleaner in one gallon of deionized water, and were
15 allowed to remain in the bath at a temperature of about 40 °C to about 50 °C for a time
16 period of about 30 minutes. This cleaning step 1814 is followed by a clean/rinse 1816
17 with deionized water.

18 [0109] The stainless steel surfaces are subsequently treated 1820 with a citric acid and
19 deionized water solution having a specific gravity of about 1.25 and a pH of about 1.8,
20 which may contain surfactants. We used CITRISURF™ 2050 available from Stellar
21 Solutions at stellarsolutions.net, which is recommended for use over a temperature range
22 from about 45°C to about 70 °C. We immersed the stainless steel surfaces in a circulation
23 bath for about 30 minutes at about 65 °C. The treatment step 1820 was followed by a
24 deionized water clean/rinse 1822 which was carried out in an immersion bath for about 15
25 minutes at a temperature ranging from about 60 °C to about 70 °C. Subsequently, the
26 stainless steel surfaces were dried 1824 in a n argon atmosphere at about 70 °C for a time
27 period of about 10 minutes.

1 [0110] The stainless steel surfaces were then heat treated 1826 at about 100 °C in a
2 pure, filtered argon gas atmosphere for a time period of about 1 hour.

3 [0111] Finally, the stainless steel surfaces are again treated 1828 with the 20 % by
4 volume nitric acid in a deionized water base for a time period of about 20 minutes to
5 about 25 minutes over a temperature range of about 45 °C to about 55°C. The treatment
6 1828 was followed by a clean/rinse 1830 with deionized water in a circulation bath for a
7 time period ranging from about 10 minutes to about 15 minutes at a temperature ranging
8 from about 65 °C to about 75°C. The clean/rinse treatment 1830 was followed by a drying
9 step 1832 using hot nitrogen gas in the manner described above.

10 [0112] The same passivation process described above can be applied to the stainless
11 steel surfaces of layers which are to be exposed to corrosive fluids in general. This may
12 be the case when the stainless steel layers are used in an area of a part containing elements
13 which cannot withstand the temperatures required for diffusion bonding and an adhesive
14 is used for bonding purposes, as previously discussed.

15 [0113] After the above passivation process, the treated parts including the passivated
16 stainless steel surfaces or layers of stainless steel which are awaiting bonding into a
17 layered substrate should be placed in protective packaging for storage. An acceptable
18 protective packaging comprises a nylon inner bag enclosed in a double bag of
19 polyethylene. The package may be pressure sealed with an inert gas on the interior or
20 may be vacuum sealed.

21 [0114] The passivation step results in chromium from the bulk of the stainless steel
22 being pulled toward exposed surfaces of the stainless steel, providing chromium
23 enhancement at the exposed surfaces. Oxidation of the chromium to form chromium
24 oxide at the exposed substrate surfaces is performed simultaneously with the chromium
25 enhancement. The chromium-rich surfaces of the stainless steel are more chemically
26 inert, and therefore more corrosion-resistant, than prior to performance of the passivation
27 step.

1 [0115] Following are the descriptions of fabrication of various fluid flow network
2 architecture components which are diffusion bonded at least in part to become part of the
3 network architecture. The first description pertains to how the basic fluid flow channels
4 are created for use in the network; this is followed by illustrations of how various devices
5 are partially or fully integrated into the network architecture which contains the basic
6 fluid flow channel; subsequently descriptions of two embodiments of fully integratable
7 devices are presented; and, finally, an entire gas pallet which illustrates the network
8 architecture (excluding the control system) is presented.

9 [0116] Figure 5A is a top view of five metal layers each of which has been patterned
10 differently for use in forming a network channel structure. The patterned metal layers
11 (510, 520, 530, 540, and 550), each exhibit through-holes which were formed using the
12 chemical or electrochemical etching previously described. These through-holes serve
13 various functions in the final gas distribution assembly. For example, certain through-
14 holes 560 and "slots" 565 are used for gas transport. Other through-holes 570 can be
15 threaded and used for attachment of surface-mounted components, or to screw together
16 several diffusion-bonded sub-units (such as structure 600 shown in Figure 6A). The total
17 assembly 580 used to form one embodiment of a channel network makes use of nine
18 layers. This assembly is shown in Figure 5B. With reference to Figure 5A, the bottom
19 layer, layer 1, includes shaped through holes 560 for gas transport. Layer 2 includes
20 additional shaped through holes 560 for gas transport. Layers 3 - 7 include shaped
21 through hole slots 565 for gas transport. Layers 8 and 9 both include shaped through
22 holes 560 for gas transport.

23 [0117] Following chemical etching to form the through-holes, two or more of the
24 metal layers (such as those shown in Figure 5A) are stacked and aligned, prior to diffusion
25 bonding. Figure 5B is a three dimensional view showing an expanded assembly of the
26 patterned metal layers shown in Figure 5A, but rotated by 180 degrees. Figure 5B shows
27 all of the layers, including layers 3 - 7 which are the patterned metal layer 530 of Figure

1 5A. A through-hole in one layer is typically aligned with a through-hole 560 or a shaped
2 through hole slot 565 in at least one adjacent layer, to form a gas flow channel running
3 through the stack of metal layers.

4 [0118] Diffusion bonding of the metal layers (such as layers 510, 520, 530, 540, and
5 550, shown in Figure 5A) is performed as described above, with respect to the
6 manufacture of the lower metal portion of the diaphragm valve, according to the process
7 conditions set forth in Table One.

8 [0119] As described with respect to the manufacture of the diaphragm valve, some
9 layers in the network architecture may be diffusion bonded, while other layers may be
10 bonded using conventional adhesives suitable for high-strength bonding of metals. The
11 choice of using either diffusion bonding or adhesive bonding depends on the ultimate
12 function of each layer within the network architecture. In some instances several layers of
13 a given pattern may be used to arrive at a particular thickness. In other instances, because
14 of the function of the layer, a diffusion bondable material may not be what is required and
15 the layer will be applied using an adhesive.

16 [0120] Following diffusion bonding (or a combination of diffusion bonding certain
17 layers and adhesive bonding other layers), the side edges 590 of the bonded structure (not
18 shown) may be machined to provide a smoother, more even surface. Machining of the
19 edges 590 (shown in the Figure 5B assembly prior to bonding) may be performed using
20 conventional machining techniques known in the art. Other post-diffusion bonding steps
21 may include roller burnishing of counter-bore sealing surfaces, tempering, hole tapping,
22 and surface treatment, such as electropolishing or chemical passivation.

23 [0121] In some embodiments of the invention, various component devices may be
24 surface mounted to a network of gas flow channels which are a part of the network
25 architecture. The component devices are typically attached to the network structure using
26 threaded pins or bolts which are screwed into threaded openings within the gas
27 distribution assembly, typically at the edges of the assembly. Shaped through holes

1 useful for this purpose are illustrated as holes 570 (threading not shown) in expanded
2 assembly 580 illustrated in Figure 5B. Component devices attached in this matter are
3 typically flush mounted on the upper surface of the diffusion bonded channel network
4 structure. Such component devices include, for example and not by way of limitation,
5 valves, filters, pressure sensors, actuators, pressure transducers, and flow controllers.
6 Surface mounting of components is described, for example, in U.S. Patent No. 5,860,676,
7 issued January 19, 1999, to Brzezicki et al.; U.S. Patent No. 6,231,260, issued May 15,
8 2001, to Markulec et al.; U.S. Patent No. 6,260,581, issued July 17, 2001, to
9 Hollingshead; and U.S. Patent No. 6,502,601, issued January 7, 2003, to Eidsmore et al.

10 [0122] A network architecture which includes both a fluid flow channel network and
11 various component devices is illustrated in Figure 6A. Figure 6A shows an integrated
12 structure 600 in which portions of the various component devices are integrated to
13 different degrees into the diffusion bonded substrate 605. Components that are well
14 suited for incorporation into and diffusion bonding with the metal layers include valves,
15 pressure sensors, flow sensors, temperature sensors, filters, pressure regulators, and check
16 valves (for example, and not by way of limitation). Figure 6A is a schematic side view of
17 a gas distribution assembly 600 which includes a number of diffusion-bonded layers
18 which for the base structure 610 (bonded layers similar to the expanded assembly shown
19 in Figure 5B), in addition to surface-mounted components 620 and 625, for example.

20 [0123] Figure 6B is a three-dimensional, break-apart view of a gas distribution
21 assembly 630, where the component devices are highly, if not fully integrated into a
22 diffusion bonded substrate. In this depicted embodiment, gas distribution assembly 630
23 includes individual, sub-units 617, 618, 619, and 621 which are diffusion bonded, while
24 other sub-units 611, 612, 613, 614, 615, and 616 are either adhesively bonded or laser
25 welded. Partially integrated components include a valve 622, proportional valve 623,
26 velocity sensor 624, filter 625, pressure sensor 626, and pressure regulator 627.

27 [0124] Figures 7A - 7E show various views of a pressure sensor 700, which is a

1 component device which can be prepared using the chemical etching and diffusion
2 bonding techniques described herein and which can be completely integrated into the gas
3 channel distribution network portion of the network architecture.

4 [0125] Figure 7A shows a schematic three dimensional view of the pressure sensor
5 700, including closed side 702; fluid entry (or exit) side 704, with opening 706 into
6 which fluids enter or exit; a getter pump 730 at the top of the unit; electrical contact pins
7 732; cap 728; and a spacer 726, which will be described later with respect to Figure 7F.

8 [0126] Figure 7B is a schematic diagram of a side view of closed side 702 of the
9 pressure sensor 700 shown in Figure 7A, with a cross-sectioning marker A – A illustrated
10 thereon. Figure 7D is a schematic diagram of the cross-sectional view A – A of the
11 pressure sensor 700 shown in Figure 7B.

12 [0127] Figure 7C is a schematic diagram of a side view of side 704 of the pressure
13 sensor 700 shown in Figure 7A, which includes entrance (or exit 706) into a channel 715
14 for fluid flow. Figure 7E is a schematic diagram of the cross-sectional view B – B of the
15 pressure sensor shown in Figure 7C.

16 [0128] Figure 7D, the section A – A view of Figure 7B, shows in detail the
17 relationship of a portion of the elements of the pressure sensor 700 after diffusion bonding
18 of various layers (which are shown in Figure 7F) to form a compact, integrated structure.
19 The integrated structure is part of a network architecture (not shown) where at least a
20 portion of the layers which make up the pressure sensor 700 extend to become portions of
21 other component devices or fluid channel networks as well. Figure 6B shows how single
22 layers within the network perform as parts of more than one component device, for
23 example. In more detail, Figure 7D shows the fluid flow channel 715 through which
24 fluids may enter (or exit), where channel 715 is created when patterned openings in an
25 assembly of layers 714, such as those shown in Figure 7F, are bonded together. Near the
26 exterior base 710 of pressure sensor 700 is a slot 713 which counteracts the effects of
27 volume changes in the fluid flow when only a portion of the fluid volume is directed

1 toward the sensing area. The portion of the fluid flow (not shown) which is sent to the
2 sensing area passes through openings 717 (shown in Figure 7E) in layer 716 into a first
3 chamber 719 beneath metal diaphragm 720. Openings 717 help to prevent sudden fluid
4 flow fluctuations. Pressure exerted upon metal diaphragm 720 by the fluid deforms metal
5 diaphragm 720 (typically fabricated from a relatively thin (typically about 0.003 inch
6 thick) layer of a material such as ELGILOY®, upward into a second chamber 723
7 beneath a dielectrically insulating (typically ceramic) disk 724 which has dual electrodes
8 744 and 746 present on its lower surface, which then passes through (not shown) to the
9 upper surface of disk 724 through openings 725 where they are contacted by electrical
10 contact pins 732. The electrically insulative disk 724 forms part of a capacitor, in
11 combination with metal diaphragm 720 and as diaphragm 720 deforms, changing the
12 spacing between elements in the capacitor, the amount of current passing through the
13 electrodes on the electrically insulative disk 724 changes. This change in electrical
14 current is an indication of a pressure change which can be monitored. Also illustrated in
15 Figure 7D are layer 712 (which includes slot 713), four fusion-bonded layers which form
16 opening 706 (conduit 715), layer 716 which contains openings 717 which provide fluid
17 contact with diaphragm 720; layer 718 which includes opening/first chamber 719; layer
18 722 which contains opening/second chamber 723; and spacer 726 which permits
19 formation of a third chamber 729 overlying ceramic disk 724. Getter pump 730 sustains a
20 vacuum in third chamber 729 overlying ceramic disk 724. The vacuum acts as a
21 reference pressure far below sensing pressures, so that changes in pressure are only one
22 side of the diaphragm. Use of the vacuum in the third chamber 729 permits a read out of
23 absolute pressure rather than a pressure relative to atmospheric pressure.

24 [0129] The pressure sensor could be designed to have the pressure in chamber 729 be
25 substantially higher than the pressure being sensed, in which case the pressure in chamber
26 729 would cause the diaphragm 720 to deform in a downward direction. Further, no
27 getter pump 730 would be required. The pressure sensor can also be used as a pressure

1 gage, relative to atmospheric pressure if desired for a particular application.

2 [0130] Figure 7E is a schematic diagram of a side view of side 704 of the pressure
3 sensor 700 shown in Figure 7A, and is the cross section B – B of Figure 7C. This view of
4 pressure sensor 700 illustrates openings 725 through which chambers 729 and 723 are
5 connected and held under vacuum.

6 [0131] Figure 7F is an exploded schematic three dimensional view of the pressure
7 sensor 700 shown in Figure 7A, illustrating the individual component layers which make
8 up the fully integratable pressure sensor. In particular, bottom layer 710 forms the
9 exterior base of the pressure sensor 700. Layer 712 includes slot 713 which counteracts
10 volume change effects, to reduce the amount of pressure drop when the fluid (not shown)
11 in the sensor 700 passes through openings 717 in layer 716, with excess fluid passing
12 through slots 721. The slots 721 work in combination with 713 to help control volume
13 effects, and therefore pressure effects of the fluid passing through openings 717. Further,
14 slots 721 are typically used to connect to flow channels within a fluid flow network.
15 Layer 718 is used to form a first chamber 719 beneath diaphragm 720 and above
16 openings 717 through which the fluid passes. The fluid in first chamber 719 presses
17 against diaphragm 720 causing a deformation of the portion of the diaphragm 720 which
18 is in contact with second chamber 723 formed within layer 722. An electrically insulating
19 (typically ceramic) disk 724 includes electrical contacts 744 and 746 present on its
20 underside 742 as shown in Figure G. These contacts pass through openings (not shown) in
21 the upper surface of disk 724 to provide contact points for the electrical contact pins 732
22 shown in Figure 7D. These contact pins 732 are electrically isolated from the general
23 metallic body of pressure sensor 700 by electrically insulating eyelets 738. The interior of
24 spacer 726 is sufficiently thick to create a third chamber 729 above the surface of disk
25 724, which is connected to chamber 723 through openings 725. The cap 728 forms the
26 major upper exterior surface of pressure sensor 700 and includes openings 727 through
27 which electrical contact pins 732, insulated by an insulating eyelet, a glass insulator, for

1 example, pass to contact electrical contacts (not shown) on the upper surface of disk 724.
2 A getter pump 730, typically fabricated from titanium, on the upper surface of cap 728 is
3 used to maintain a steady state vacuum in third chamber 729 and in second chamber 723
4 at a given temperature.

5 [0132] The typical thickness of the metal layers in the multilayered pressure sensor
6 700 is about 0.025 inches. The majority of the layers are stainless steel (typically series
7 400 stainless steel). The diaphragm 720 typically has a thickness of about 0.003 inches,
8 and is fabricated from ELGILOY® or a similar nickle/cobalt/chrome alloy which
9 provides a more “spring like” behavior. Electrical contact pins 732 are typically
10 fabricated from copper, and getter pump 730 typically contains a material such as
11 titanium, which soaks up free fluid molecules from third cavity 729 and second cavity
12 723.

13 [0133] Figure 8A is a schematic break-away view of a starting structure 800 for
14 forming a layered substrate 830 which includes a fully integratable in-line filter 850
15 (shown in Figures 8C and 8D). Figure 8A shows a series of layers of the kind which are
16 shown in Figures 5A and 5B. Figure 8A is used to illustrate how a totally integratable
17 filter can be formed in a space within a fluid flow network, so that the fluid flow will be
18 filtered in line as the fluid passes through the network architecture. The layers 808
19 through 816 each contain a slot 807 into which a sinterable media 848 will be placed.
20 Typically, sinterable media 848 in a green state is placed in a block or shaped structure
21 805 on the upper surface of layer 806, so that when all of the layers are compressed, the
22 sinterable media 848 will pass through all of the slots 807 and fill a space made by the
23 slots in the matter shown in Figures 8C and 8D.

24 [0134] Figure 8B is a schematic showing a top view of a diffusion bonded layered
25 substrate 830 showing the top layer 822, fluid entrance 832 and fluid exit 834. Figure 8B
26 also is marked to show cross-sectional marker A – A.

27 [0135] Figure 8C is a schematic of the cross-sectional view of layered substrate

1 structure 830. During the diffusion bonding of layered structure 830, the sinterable media
2 848 has been forced to fill a defined space between fluid entrance 832 and fluid exit 834.

3 The sintered media forms an in-line filter 850 for filtering out particulates which may
4 enter the fluid flow channel 836 of layered structure 830. Layered structure 830 may be
5 part of a larger layered structure (not shown), or component devices (not shown) such as
6 valves may be attached over fluid entrance opening 832 and fluid exit opening 834.

7 [0136] Layers 804 and 820, shown in Figures 8C and 8D (which is a more three-
8 dimensional view of cross section A – A) are typically fabricated from ELGILOY® to
9 provide a hard sealing surface during and after the diffusion bonding of structure 830.
10 Other layers in the structure may be series 400 stainless steel, for example and not by way
11 of limitation. The thickness of an ELGILOY layer may be in the range of 0.004 inches,
12 by way of example and not by way of limitation, compared with the stainless steel layers
13 which are typically in the range of about 0.025 inches, by way of example and not by way
14 of limitation.

15 [0137] The ELGILOY® layers can be used as the diaphragm 302 of the valve 300
16 previously described, as well as the diaphragm 720 for the sensor 700, and also to provide
17 the hard sealing surface for counterbores used for surface mount components.

18 [0138] Figure 9A is a top view of an integrated fluid delivery system 900 which
19 includes a number of gas distribution assemblies (gas sticks) 910 with surface-mounted
20 component devices (similar to those shown in Figure 6B). Integrated fluid delivery
21 system 900 is mounted to base plate 920, and also includes input manifolds 930 and
22 output manifold 940. Figure 9B is a three-dimensional side view of the integrated fluid
23 delivery system 900 shown in Figure 9A, which illustrates the amount of integration of
24 the individual component devices into the diffusion bonded substrate.

25 [0139] An integrated fluid delivery system described above and shown in Figures 9A
26 and 9B can be used in conjunction with any processing equipment which requires the use
27 of various gases during a manufacturing process. With respect to semiconductor

1 processing, for example and not by way of limitation, the fluid delivery system may be
2 used in combination with etch chambers, chemical vapor deposition (CVD) chambers,
3 and physical vapor deposition (PVD) chambers.

4 [0140] One of the advantages of the integrated fluid delivery system 900 illustrated
5 in Figure 9B is that individual gas distribution assemblies (gas sticks) 910 may be
6 removed from the fluid delivery system and replaced with a new gas distribution assembly
7 at a reasonable cost. This makes it possible to minimize the down time of the entire
8 semiconductor processing system when one or more fluid delivery component devices
9 fails to perform for some reason. An individual gas distribution assembly may be
10 removed and repaired off line, without the need for costly plumbing and replumbing time.
11 If the individual gas distribution assembly cannot be repaired, the materials of
12 construction may be recycled.

13 [0141] The conserved space, integrated gas distribution network architectures of the
14 invention are cheaper to fabricate than the conventional larger-sized systems because they
15 require much less material for fabrication, and because the manufacturing processes
16 (chemical etching and diffusion bonding) used to fabricate the assemblies are scalable in
17 size to meet the application and scalable in terms of production quantity, to provide cost
18 economy.

19 [0142] The diffusion bonding techniques described above can also be used to attach a
20 semiconductor processing chamber component to a fluid handling network component.
21 The fluid handling network component may be a gas distribution assembly, or may be any
22 of the component devices listed previously, such as, for example, manually operated
23 valves, automatic valves, pressure and temperature sensors, flow controllers, filters,
24 pressure regulators, check valves, metering valves, needle valves, and purifiers. The
25 semiconductor processing chamber component to which a fluid handling network
26 component is bonded may be, for example and not by way of limitation, a flange or entry
27 portal to an etch chamber, a chemical vapor deposition (CVD) chamber, or a physical

1 vapor deposition (PVD) chamber, for example.

2 [0143] The above-described embodiment is provided to enable one skilled in the art to
3 understand the concepts which are disclosed and claimed herein, and is not intended to
4 limit the scope of the present invention. One skilled in the art, in view of the disclosure in
5 this application may expand the concepts and the materials which may be used for various
6 elements of the layered fluid channels, sensors, actuators, and valves, to correspond with
7 the subject matter of the invention claimed below.